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Virkler

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(54) **MECHANISM AND METHOD FOR RAPID RESPONSE CLEARANCE CONTROL**

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| ***F04D 29/52*** | (2006.01) |

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

CPC .......... F01D 11/20; F01D 11/22; F01D 25/24; F01D 21/003

USPC ............................................... 415/128, 173.2

See application file for complete search history.

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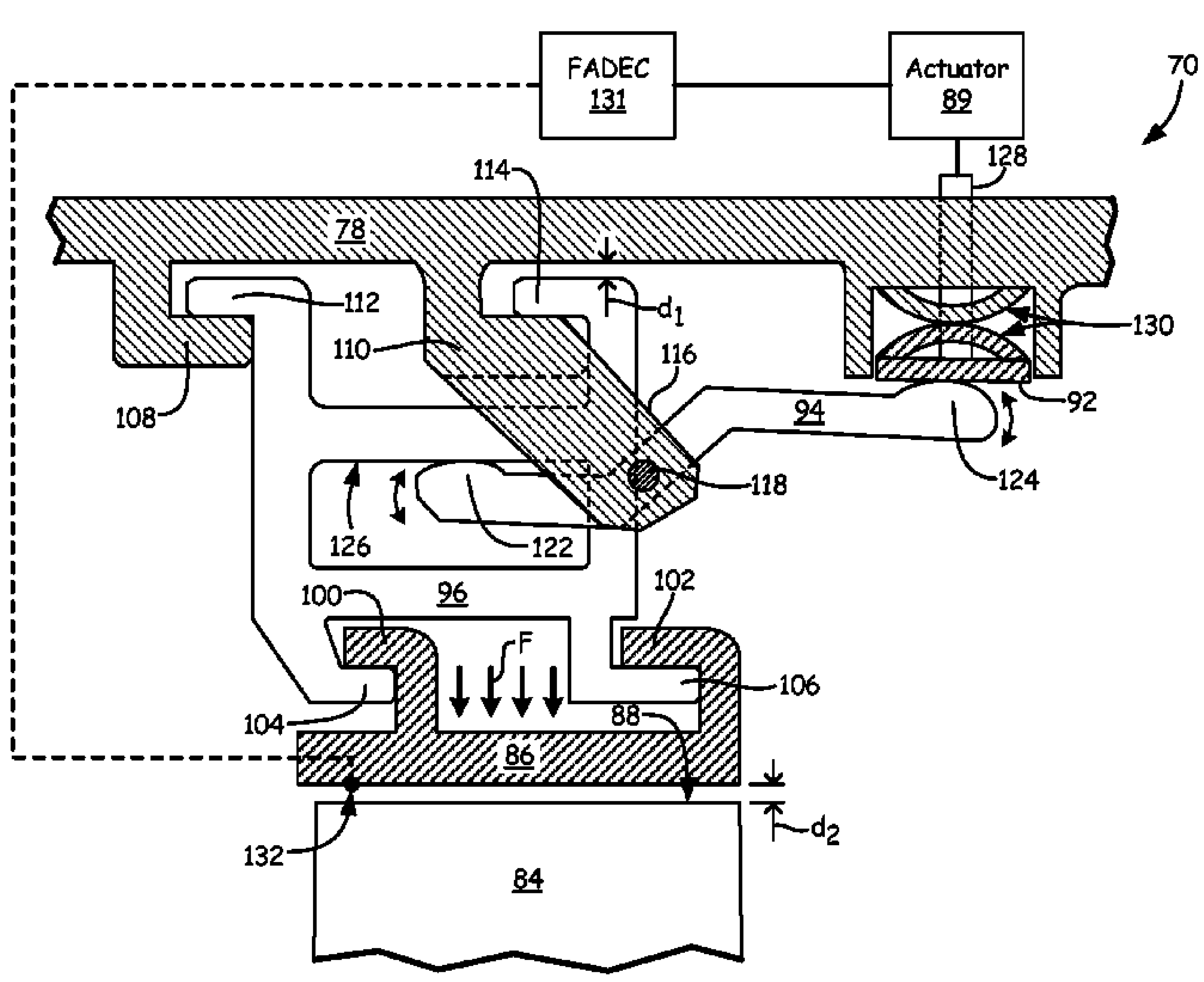
(57) **ABSTRACT**

A clearance control assembly for providing clearance control between a blade outer air seal and an airfoil tip of a gas turbine engine includes an outer case, a first blade outer air seal carrier, a blade outer air seal, an actuator, a load-applying member, and a lever. The first blade outer air seal carrier is positioned radially inward of the outer case. The blade outer air seal is positioned radially inward of and mounted to the blade outer air seal carrier. The load-applying member is positioned to be acted upon by the actuator during operation of the actuator. The lever is connected to the case and is operably in contact with the load-applying member and the first blade outer air seal carrier.

**18 Claims, 6 Drawing Sheets**



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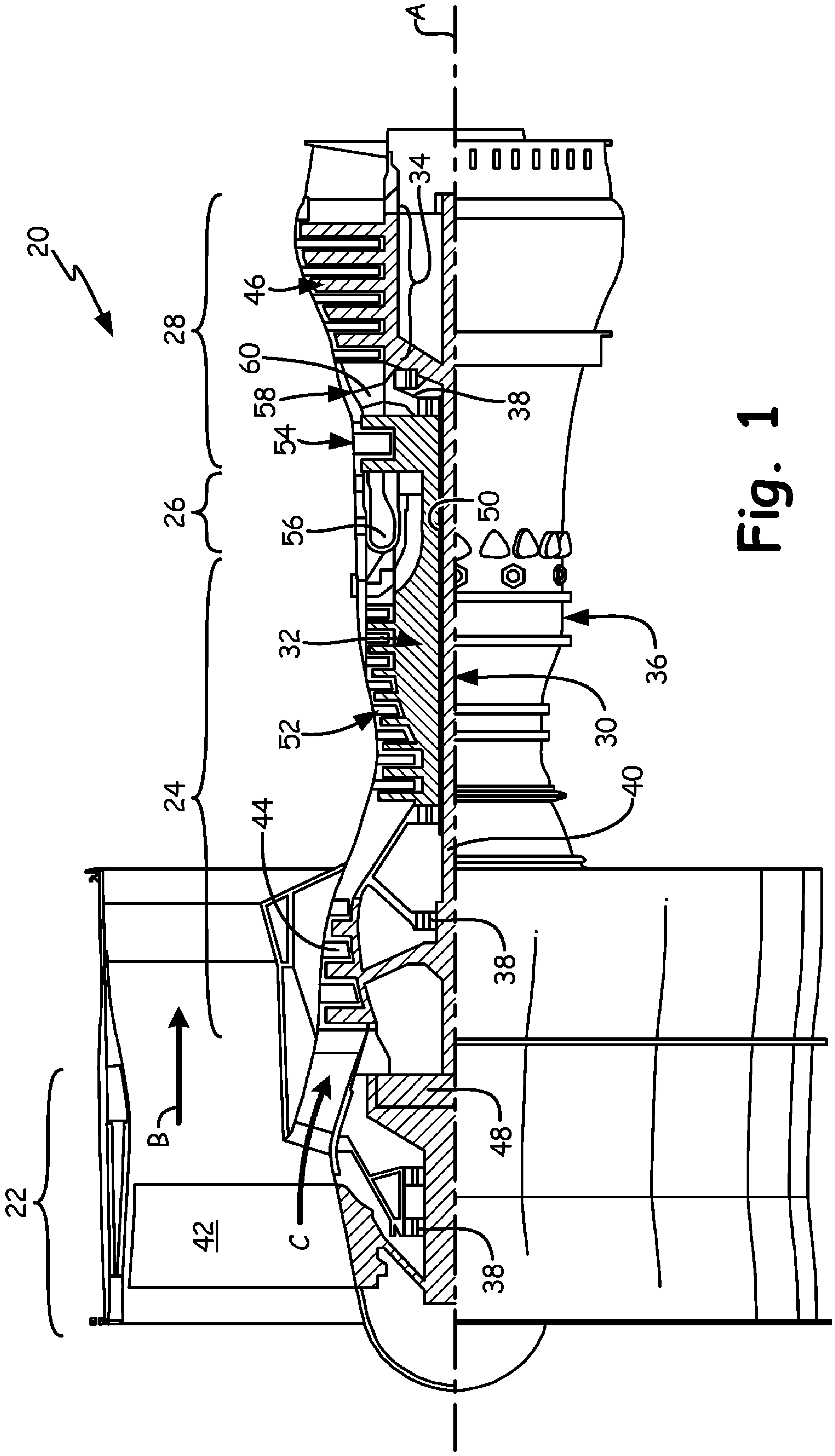



Fig. 1

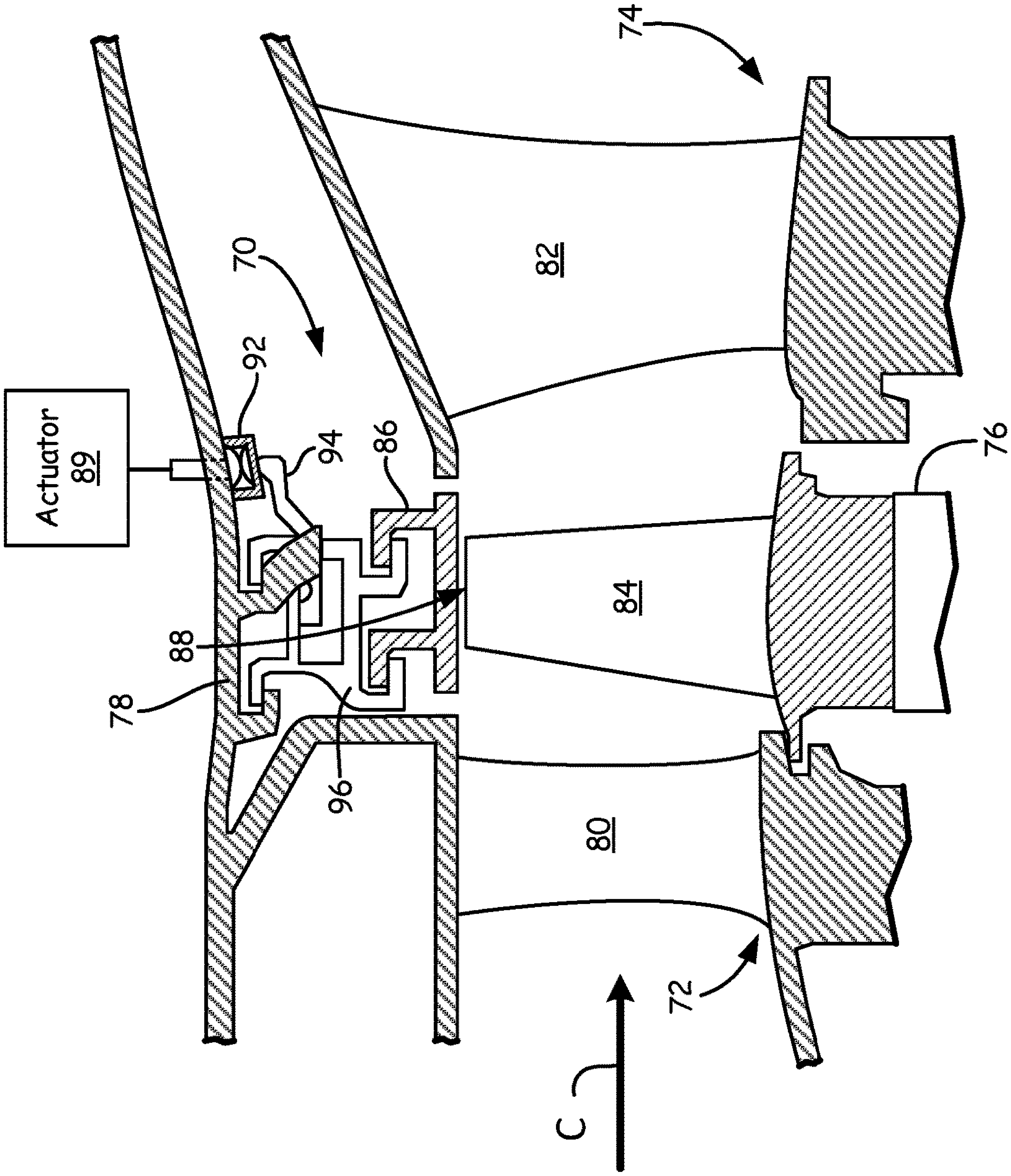
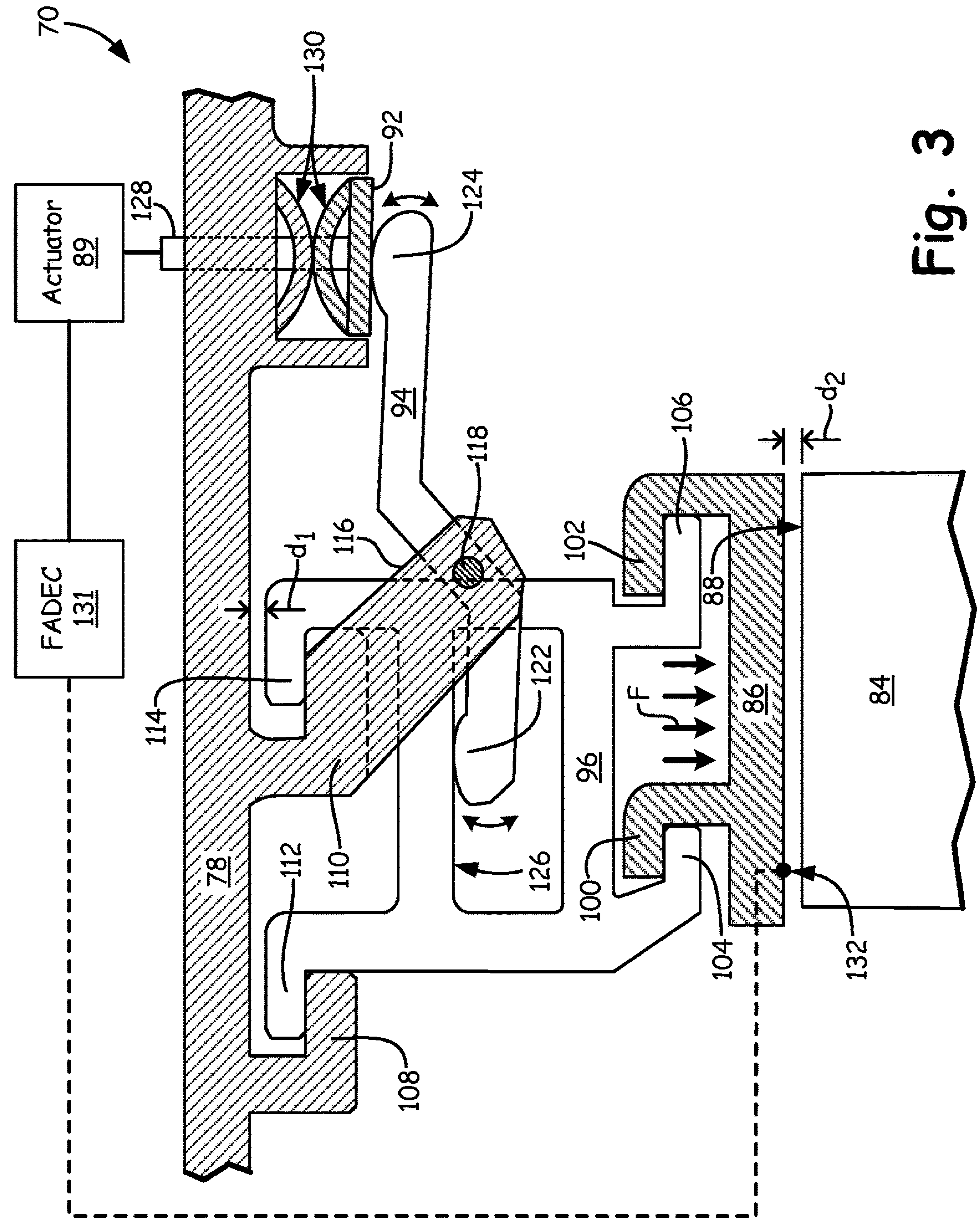



Fig. 2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92
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d1
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122
F
86
84
96
78
112
110
126
100
104
132
108

Fig. 3

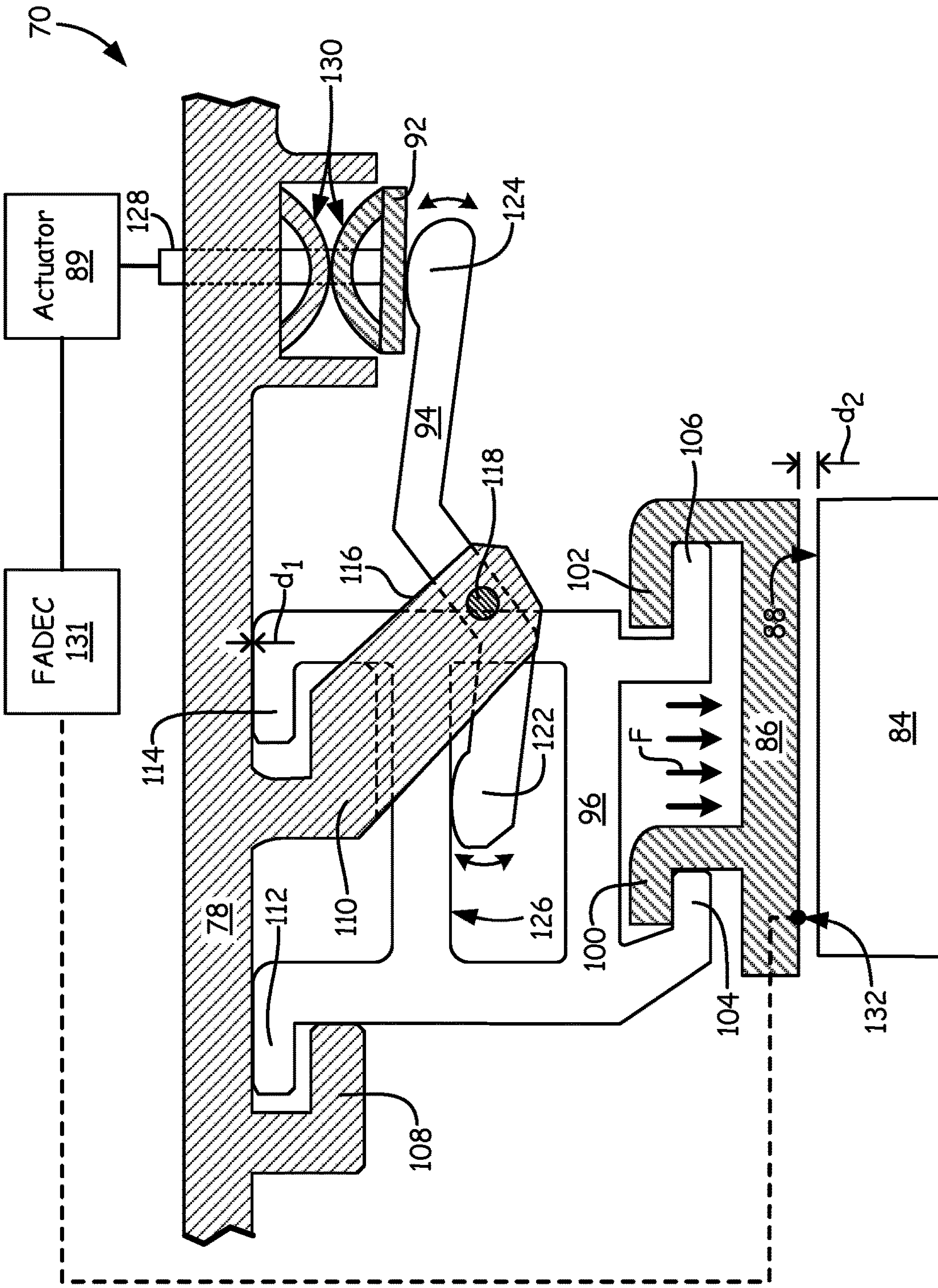
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Fig. 4

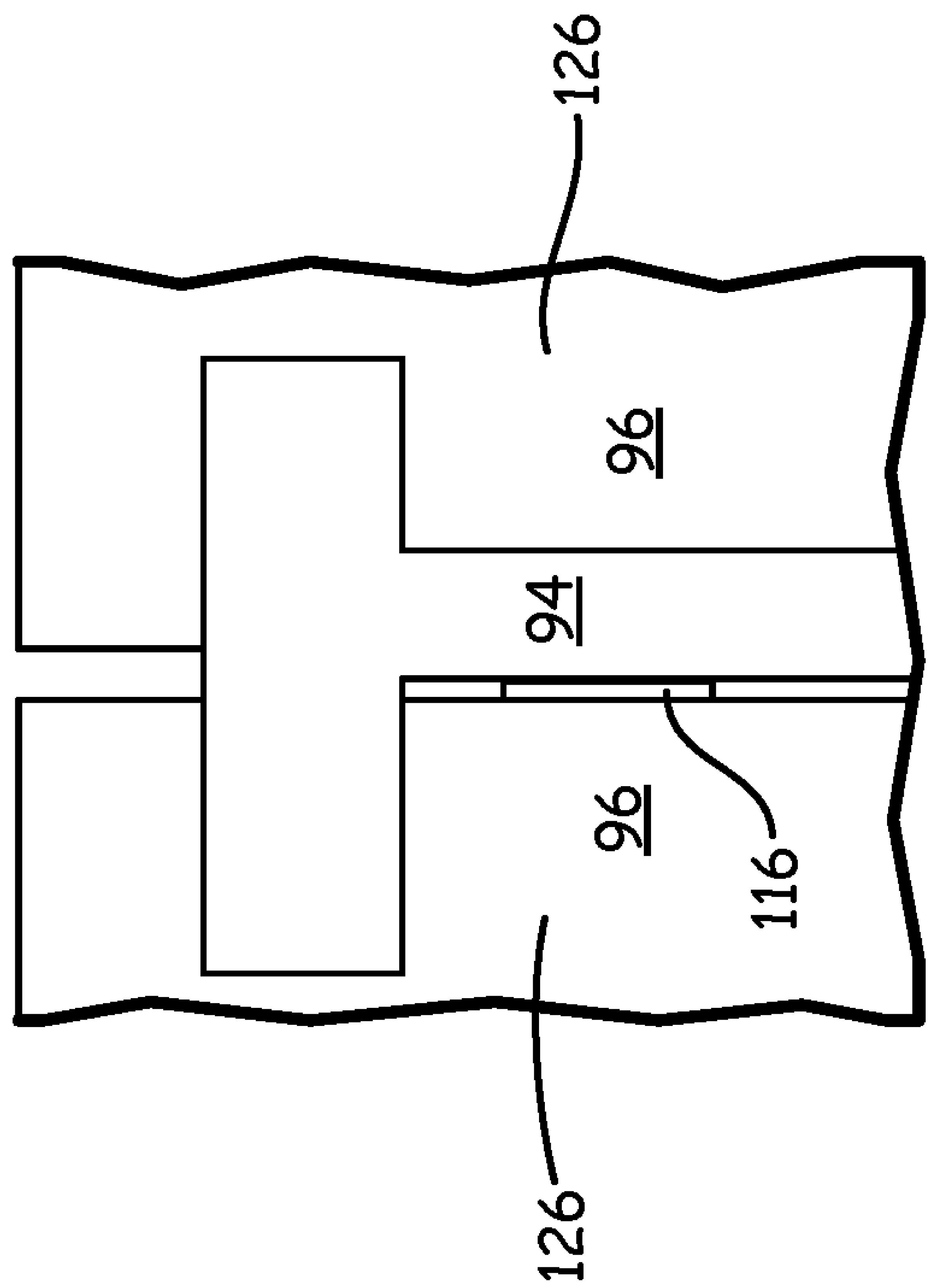
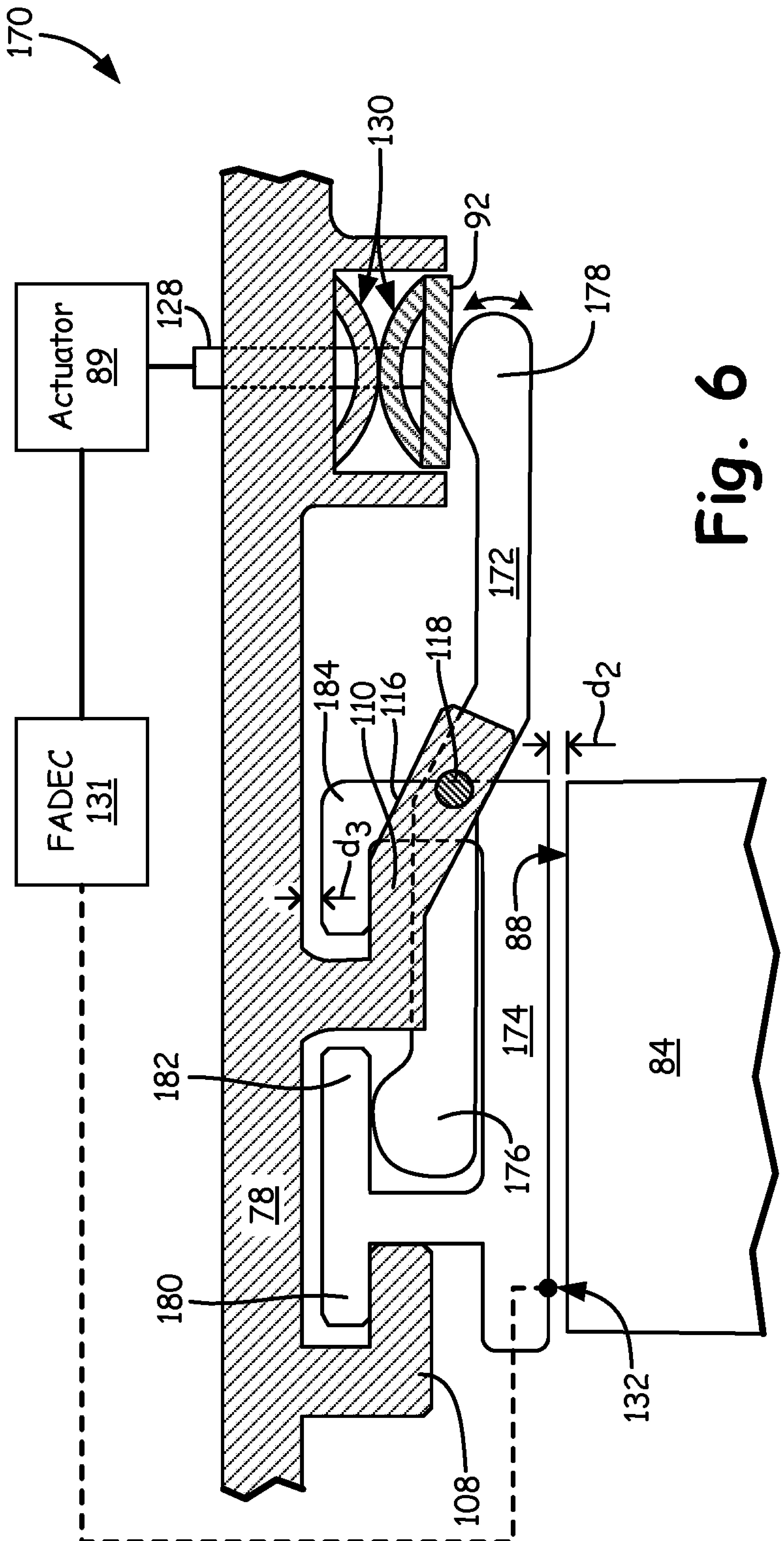



Fig. 5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89
172
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116
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88
182
174
84
176
78
180
132
108

Fig. 6

# MECHANISM AND METHOD FOR RAPID RESPONSE CLEARANCE CONTROL

## BACKGROUND

The present disclosure relates generally to blade outer air seals (BOAS) used in gas turbine engines, and more particularly to providing rapid response clearance control for the same.

Rotor tip clearance control is necessary for achieving improvements in turbomachinery efficiency and fuel consumption. It is desirable to minimize the clearance between a rotor tip and a static outer shroud seal (e.g., BOAS), while reducing the potential for tip rubbing during operation. This can be achieved by various means of active clearance control (ACC), which utilizes fluid, generally bleed air from a compressor exit and/or bypass duct of a gas turbine engine, to control the thermal expansion or contraction, and thereby the inner diameter, of an outer case. ACC is commonly used during cruising portions of a flight. Because thermal response can be slow, conventional ACC systems are generally not well suited to rapid throttle operations (e.g., snap accelerations, rapid re-accelerations, and maneuvers), which immediately add mechanical growth due to acceleration to the existing thermal growth of the rotor disk. During rapid throttle operations, the rotor and, in particular, the airfoil, can expand at a significantly higher rate than the case, requiring that tip clearances be set higher than desired to limit tip rubbing.

Clearance control assemblies capable of providing rapid response to thermal and mechanical growth are needed to reduce tip clearance during high throttle operations while reducing or preventing tip rub.

## SUMMARY

In one aspect, a clearance control assembly for providing clearance control between a blade outer air seal and an airfoil tip of a gas turbine engine includes an outer case, a first blade outer air seal carrier, a blade outer air seal, an actuator, a load-applying member, and a lever. The first blade outer air seal carrier is positioned radially inward of the outer case. The blade outer air seal is positioned radially inward of and mounted to the blade outer air seal carrier. The load-applying member is positioned to be acted upon by the actuator during operation of the actuator. The lever is connected to the case and is operably in contact with the load-applying member and the first blade outer air seal carrier.

In another aspect, a method of controlling a clearance between a blade outer air seal and an airfoil tip of a gas turbine engine includes pivoting a lever operably in contact with an axially extending surface of a blade outer air seal or a blade outer air seal carrier and moving the blade outer air seal in relation to the airfoil tip. The lever is pivoted to adjust the radially outward force applied against the axially extending member. The lever is pivoted to 1) increase a radially outward force applied to the axially extending surface or 2) reduce a radially outward force applied to the axially extending surface. The blade outer air seal is 1) lifted in relation to the airfoil tip or 2) lowered in relation to the airfoil tip.

In yet another aspect, a clearance control assembly for providing clearance control between a blade outer air seal and an airfoil tip of a gas turbine engine includes an outer case having axially separated first and second hooks, a blade outer air seal, an actuator, a load-applying member, and a lever. The first and second hooks are positioned radially inward of the outer case. The blade outer air seal is positioned radially inward of the outer case and has third and fourth hooks. The third hook is positioned between the first hook and the inner surface of the outer case and the fourth hook is positioned between the second hook and the inner surface of the outer case. The load-applying member is positioned to be acted upon by the actuator during operation of the actuator. The lever is connected to the case and operably in contact with the load-applying member and an axially extending surface of the blade outer air seal.

The present summary is provided only by way of example, and not limitation. Other aspects of the present disclosure will be appreciated in view of the entirety of the present disclosure, including the entire text, claims and accompanying figures.



## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a quarter-sectional view of a gas turbine engine.

FIG. **2** is a schematic view of a portion of the gas turbine engine with a clearance control assembly.

FIG. **3** is a cross-sectional view of the clearance control assembly in a first position.

FIG. **4** is a cross-sectional view of the clearance control assembly in a second position.

FIG. **5** is a cross-sectional view of another embodiment of the clearance control assembly.

FIG. **6** is a schematic view of a portion of the clearance control assembly.

While the above-identified figures set forth embodiments of the present invention, other embodiments are also contemplated, as noted in the discussion. In all cases, this disclosure presents the invention by way of representation and not limitation. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the invention. The figures may not be drawn to scale, and applications and embodiments of the present invention may include features, steps and/or components not specifically shown in the drawings.

## DETAILED DESCRIPTION

FIG. **1** is a quarter-sectional view of a gas turbine engine **20** that includes fan section **22**, compressor section **24**, combustor section **26** and turbine section **28**. Alternative engines might include an augmenter section (not shown) among other systems or features. Fan section **22** drives air along bypass flow path B while compressor section **24** draws air in along core flow path C where air is compressed and communicated to combustor section **26**. In combustor section **26**, air is mixed with fuel and ignited to generate a high pressure exhaust gas stream that expands through turbine section **28** where energy is extracted and utilized to drive fan section **22** and compressor section **24**.

Although the disclosed non-limiting embodiment depicts a turbofan gas turbine engine, it should be understood that the concepts described herein are not limited to use with turbofans as the teachings may be applied to other types of turbine engines; for example a low-bypass turbine engine, or a turbine engine including a three-spool architecture in which three spools concentrically rotate about a common axis and where a low spool enables a low pressure turbine to drive a fan via a gearbox, an intermediate spool that enables an intermediate pressure turbine to drive a first compressor of the compressor section, and a high spool that enables a high pressure turbine to drive a high pressure compressor of the compressor section.

The example engine **20** generally includes low speed spool **30** and high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided.

Low speed spool **30** generally includes inner shaft **40** that connects fan **42** and low pressure (or first) compressor section **44** to low pressure (or first) turbine section **46**. Inner shaft **40** drives fan **42** through a speed change device, such as geared architecture **48**, to drive fan **42** at a lower speed than low speed spool **30**. High-speed spool **32** includes outer shaft **50** that interconnects high pressure (or second) compressor section **52** and high pressure (or second) turbine section **54**. Inner shaft **40** and outer shaft **50** are concentric and rotate via bearing systems **38** about engine central longitudinal axis A.

Combustor **56** is arranged between high pressure compressor **52** and high pressure turbine **54**. In one example, high pressure turbine **54** includes at least two stages to provide a double stage high pressure turbine **54**. In another example, high pressure turbine **54** includes only a single stage. As used herein, a “high pressure” compressor or turbine experiences a higher pressure than a corresponding “low pressure” compressor or turbine.

The example low pressure turbine **46** has a pressure ratio that is greater than about 5. The pressure ratio of the example low pressure turbine **46** is measured prior to an inlet of low pressure turbine **46** as related to the pressure measured at the outlet of low pressure turbine **46** prior to an exhaust nozzle.

Mid-turbine frame **58** of engine static structure **36** is arranged generally between high pressure turbine **54** and low pressure turbine **46**. Mid-turbine frame **58** further supports bearing systems **38** in turbine section **28** as well as setting airflow entering low pressure turbine **46**.

The core airflow C is compressed by low pressure compressor **44** then by high pressure compressor **52** mixed with fuel and ignited in combustor **56** to produce high speed exhaust gases that are then expanded through high pressure turbine **54** and low pressure turbine **46**. Mid-turbine frame **57** includes airfoils/vanes **60**, which are in the core airflow path and function as an inlet guide vane for low pressure turbine **46**. Utilizing vanes **60** of mid-turbine frame **58** as inlet guide vanes for low pressure turbine **46** decreases the length of low pressure turbine **46** without increasing the axial length of mid-turbine frame **58**. Reducing or eliminating the number of vanes in low pressure turbine **46** shortens the axial length of turbine section **28**. Thus, the compactness of gas turbine engine **20** is increased and a higher power density may be achieved.

Each of the compressor section **24** and the turbine section **28** can include alternating rows of rotor assemblies and vane assemblies (shown schematically) that carry airfoils that extend into the core flow path C. To improve efficiency, static outer shroud seals (not shown), such as a blade outer air seal (BOAS), can be located radially outward from rotor airfoils to reduce tip clearance and losses due to tip leakage.

FIG. **2** illustrates a portion of a gas turbine engine, such as, but not limited to, gas turbine engine **20** of FIG. **1**, having clearance control assembly **70**. The portion of the gas turbine engine illustrated in FIG. **2** is intended to be non-limiting. It will be understood by one skilled in the art that clearance control assembly **70** can be installed in both compressor and turbine sections (**24**, **28**) of gas turbine engine **20** or other gas turbine engines. The portion of the gas turbine engine illustrated in FIG. **2** has stator assemblies **72** and **74**, rotor **76**, and case **78**. Stator assemblies **72** and **74** can each have a plurality of airfoils **80** and **82**, respectively, to direct core airflow C. Rotor **76** can have a plurality of airfoils **84** to create or extract energy from core airflow. Case **78** can be an annular ring configured to house stator assemblies **72** and **74**, rotor **76**, and clearance control assembly **70**. Clearance control assembly **70** can include a static outer shroud seal or BOAS **86** configured to reduce core airflow leakage across rotor tip **88**, an actuator **89**, load-applying member **92**, and lever **94**. Clearance control assembly **70** can optionally include seal carrier **96**, as shown in FIG. **2**. BOAS **86** can be located radially inward of case **78** and radially outward of rotor tip **88**. Conventionally, a plurality of segmented BOAS **86** can be used, collectively forming a ring around rotor **76** to seal multiple airfoils **84**. As illustrated in FIG. **2**, BOAS **86** can be mounted to seal carrier **96**, which can be positioned between case **78** and BOAS **86**. Seal carrier **96** can be an annular ring or a segment configured to receive one or more BOAS **86**. A plurality of seal carriers **96** can form a segmented ring within an inner diameter of case **78**. In an alternative embodiment, BOAS **86** can be mounted to case **78** directly (illustrated in FIG. **6**).

During operation of the gas turbine engine, rotor **76** and airfoil **84** can expand radially outward due to increased temperatures and centrifugal load. Static components, such as case **78** and stator assemblies **72** and **74**, as well as clearance control assembly **70**, can also experience thermal growth. The rate of thermal expansion for each component can vary significantly, with the rate of thermal expansion of airfoil **84** generally being greater than the rate of thermal expansion of both rotor **76** and case **78**. Clearance control assembly **70** can be used to adjust the radial position of BOAS **86** to minimize clearance between BOAS **86** and rotor tip **88**, while limiting the potential for tip rub against BOAS **86**. Lever **94** can be used to apply a radially outward force against seal carrier **96** to cause seal carrier **96** and thereby BOAS **86** to move radially outward away from rotor tip **88**. Clearance control assembly **70** can provide rapid response to a changes in tip clearance due to variations in the thermal environment and centrifugal load of rotor **76** and airfoil **84**. The ability to provide rapid response is particularly important during high throttle operations, such as snap accelerations, rapid re-accelerations, and maneuvers, which immediately add mechanical growth due to acceleration to the existing thermal growth of rotor **76** and airfoil **84**. Without a rapid response mechanism for clearance control during high throttle operations, tip clearances must be set sufficiently high to avoid the detrimental effects of tip rub under different operational conditions. Setting high clearances to avoid tip rub during high throttle operations results in reduced efficiency due to increased tip leakage during lower throttle operations (e.g., during a cruise portion of a flight). A plurality of clearance control assemblies **70** can be positioned circumferentially around and within case **78** to control rotor tip clearance between each rotor tip **88** and BOAS **86**. While FIG. **2** illustrates a mechanism for providing rapid response clearance control, it will be understood by one skilled in the art that traditional active clearance control (ACC) mechanisms (not shown), but particularly suited to the cruising portion of a mission, can be optionally used in addition to clearance control assembly **70**.

FIGS. **3** and **4** are cross-sectional views of the clearance control assembly **70** of FIG. **2**. FIG. **3** illustrates BOAS **86** located in a radially innermost position. FIG. **4** illustrates

BOAS **86** in a radially outermost position. As illustrated in FIGS. **3** and **4**, BOAS **86** has forward and aft hooks **100** and **102**, respectively, which can be mounted into respective forward and aft hooks **104** and **106** of seal carrier **96**. Hooks **100** and **102** can extend radially outward from BOAS **86**, while hooks **104** and **106** can extend radially inward from seal carrier **96**. Each BOAS **86** can have a plurality of hooks **100** and **102**, and each seal carrier **96** can have a plurality of mating hooks **104** and **106**. As illustrated in FIGS. **3** and **4**, hooks **100** and **102** can face forward, while hooks **104** and **106** can face aftward; however, it will be understood by one skilled in the art that the orientation of hooks **100**, **102**, **104**, and **106**, as well as the position can be modified as needed to optimize mounting for operation or to improve ease of assembly and disassembly. Ease of assembly is particularly important for BOAS **86** as well as seal carriers **96** in the turbine section of the gas turbine engine where exposure to high temperature gas flow from the combustor limits the lifetime of the parts and necessitates periodic replacement. However, while the hook-style mounts illustrated in FIGS. **3** and **4** can increase ease of assembly, it will be understood by one skilled in the art that other fastening mechanisms can be used (e.g., nut, bolt, screw, rivet, weld). A secondary cooling airflow (not shown) can provide a biasing force (F) that biases BOAS **86** to seal carrier **96** during operation of the gas turbine engine. Therefore, fastening mechanisms in addition to hooks **100**, **102**, **104**, and **106** are unnecessary to secure BOAS **86** to seal carrier **96**.

Seal carrier **96** can be mounted to case **78** in a similar fashion to how BOAS **86** is mounted to seal carrier **96**. Case **78** can have radially inward extending hooks **108** and **110**, which can receive radially outward extending hooks **112** and **114** of seal carrier **96**. As illustrated in FIGS. **3** and **4**, hooks **112** and **114** can be located in a forward and aft portion on seal carrier **96**. Seal carrier **96** can include a plurality of hooks **112** and **114** configured to mount into a plurality of mating hooks **108** and **110**. Hooks **108** and **110** can extend substantially congruent with an inner surface of the outer case. As illustrated in FIGS. **3** and **4**, hooks **108** and **110** face aftward, while hooks **112** and **114** face forward. It will be understood by one skilled in the art that the orientation and positioning of hooks **108**, **110**, **112**, and **114** can be modified to optimize stability during operation and improve ease of assembly and disassembly. A space, labeled as distance $d_1$ in FIGS. **3** and **4** can allow for the radially outward movement of seal carrier **96**, and thereby BOAS **86**, which is enabled by the use of the non-fixed hook-style mounting illustrated in FIGS. **3** and **4**. For certain applications, distance $d_1$ can range from approximately 0.5-1.8 mm (0.02-0.07 inches). However, it will be understood by one skilled in the art that distance $d_1$ can vary depending on the scale of the engine, magnitude of maneuvers and amount of interaction to due to re-acceleration closedown.

Seal carrier **96**, and thereby BOAS **86**, can be moved radially outward by lever **94** when lever **94** is acted upon by load-applying member **92**. Lever **94** can be secured to (or relative to) case **78**. Case **78** can include connection member **116**, which can attach to lever **94** at fulcrum **118**. As illustrated in FIGS. **3** and **4**, connection member **116** can extend radially inward from a lateral surface of hook **110**. Connection member **116** can be integrally formed with hook **110** or can be a separate element secured by a fastener (e.g., nut, bolt, rivet, screw, weld). Although in the illustrated embodiment, the position of hook **110** is suitable for locating connection member **116** relative to fulcrum **118**, in alternative embodiments, connection member **116** can extend from hook **108** or another portion of case **78**. For segmented seal carriers **96**, connection member **116** can be located on a hook adjacent an edge of seal carrier **96**, such that connection member **116** can extend into a gap between adjacent to seal carriers **96**. While connection member **116** can secure lever **94** to case **78**, lever **94** is free to pivot about fulcrum **118** to move seal carrier **96** and BOAS **86**.

Lever **94** can have opposite ends **122** and **124**. End **122** can be radially inward of and operably in contact with axial extending surface **126** (e.g., of seal carrier **96**). End **124** can be operably in contact with load-applying member **92**. During operation, load-applying member **92** can be acted upon by plunger **128**, which can be controlled by actuator **89** outside of case **78**. Use of lever **94** allows for the positioning of actuator **89** and associated case penetration points outside of the rotor blade containment section. In this manner, clearance control assembly **70** does not compromise the rotor blade containment section of the gas turbine engine. Additionally, use of lever **94** can provide mechanical advantage based on the position of fulcrum **118** and reduce actuation loads as compared to other actuator controlled clearance control systems. FIGS. **3** and **4** illustrate actuator **89** (e.g., solenoid, hydraulic, or other suitable linear actuator) with plunger **128**, which extends through case **78**. In alternative embodiments, actuator **89** can be a rotational actuator operably connected to a cam or other mechanism capable of moving load-applying member **92**.

Actuator **89** can be selectively operated (by suitable controls) to cause plunger **128** to extend and retract. During extension, plunger **128** acts on load-applying member **92**, which in turn applies a radially inward force on lever end **124**, causing lever **94** to pivot about fulcrum **118**. When plunger **128** is retracted, load-applying member **92** and lever **94** are returned to a primary position. Biasing member **130**, which can include one or more coil springs, Belleville washers, or other type of biasing members as known in the art, can be used to provide a minimal load throughout the travel range of load-applying member **92** to help avoid a zero load condition and limit vibration and rocking of lever **94**. Low friction bushings or rolling element bearings can additionally be employed to reduce friction. Lever ends **122** and **124** can have a crowned, spherical, or cylindrical outer contact surface which can roll upon axially extending surface **126** and load-applying member **92**, respectively, when lever **94** pivots. The crowned surfaces can reduce friction that would be associated with movement of flat surfaces against axially extending surface **126** and load-applying member **92**. The position of fulcrum **118** can be set based on balancing moments. The point to which lever **94** axially extends along axially extending surface **126** can be set to limit rocking. Lever **94** should be capable of moving seal carrier **96** without significantly rocking seal carrier **96**.

As lever **94** pivots, lever end **122** can apply a radially outward force on axially extending surface **126** of seal carrier **96**. The radially outward force can lift or move seal carrier **96** radially outward, which in turn lifts or moves BOAS **86** away from rotor tip **88** to prevent tip rub. As illustrated in FIG. **4**, when seal carrier **96** is in a radially outermost position, hooks **112** and **114** of seal carrier **96** can contact an inner surface of case **78**, reducing distance $d_1$ to approximately zero. The radial position of seal carrier **96** is limited by hooks **108** and **110** and the inner surface of case **78**. However, the radial position of seal carrier hooks **112** and **114** within the space between hooks **108** and **110** and case **78** is not limited. In other words, seal carrier **96** can be positioned in a radially innermost position, a radially outermost position, and any radial position therebetween. Generally, the radially innermost position can accommodate cruising portions of a mission, while the radial outermost position accommodates various high throttle operations or maneuvers. Radial positions therebetween can be appropriate for operations that do not require full radially outward movement, but require some degree of radially outward movement to avoid tip rub.

Radial positions of seal carrier **96** can be preset based on known conditions in the gas turbine engine. In such case, actuator **89** can be in communication with a full authority digital electronic control system (FADEC) **131** or other dedicated control system, which can initiate operation of actuator **89** according to known tip clearance requirements based on operating temperatures (thermal environment) and engine acceleration or speed. For example, during a rapid acceleration, FADEC **131** can communicate with actuator **89** to position seal carrier **96** in a predetermined radial position based on earlier testing analysis. The predetermined radial position may or may not provide the optimum tip clearance if the position is a conservative value selected from a range of values obtained during testing. Alternatively, FADEC **131** can be in communication with sensors embedded within various components of clearance control assembly **70**. Sensors can include, but are not limited to, capacitance probes, which can measure the distance between two components in real time. For example, sensor **132** can be used to determine tip clearance, shown as $d_2$ in FIGS. **3** and **4**, when embedded in a radially inner surface of BOAS **86**. Use of sensors can enable real-time feedback for clearance control to optimize tip clearance throughout all operations of the gas turbine engine and improve efficiency.

A plurality of clearance control assemblies can be positioned around the circumference and within case **78** to control tip clearance. Generally, one lever **94** can be used to control the radial position of one or more BOAS **86**. Each of the plurality of seal carriers **96** can hold one or more BOAS **86** and each lever **94** can act upon one or more seal carriers **96**. FIG. **5** illustrates a schematic view of lever **94** looking radially outward from a position radially inward of lever **94**. Lever **94** can have a T-shape, which enables lever **94** to contact axially extending surfaces **126** of adjacent seal carriers **96**. In this manner, one lever **94** can be positioned between each pair of seal carriers **96**. When pivoted simultaneously and to the same position, levers **94** can limit rocking of seal carriers **96** and BOAS **86**.

FIG. **6** illustrates seal assembly **170**, which is an alternative embodiment of clearance control assembly **70**. Clearance control assembly **170** operates in similar fashion to clearance control assembly **70** without use of seal carrier **96**. As illustrated in FIG. **6**, lever **172** acts on BOAS **174** directly. Similar to lever **94** illustrated in FIGS. **3** and **4**, lever **172** has opposite ends **176** and **178**, which have crowned, spherical, or cylindrical surfaces for contacting inner radial surfaces of BOAS **174** and load-applying member **92**, respectively. Lever **172** can have a slightly different shape than lever **94** suited to the differences orientation and positioning of surrounding structures. Lever **172** can be connected to connecting member **116** at fulcrum **118**. Connecting member can extend from case hook **110** or other suitable structure connected with case **78**.

BOAS **174** can have three hooks (**180**, **182**, and **184**) as opposed to two hooks as disclosed in FIGS. **3** and **4**. Hooks **180** and **182** can form a T-shape adjacent the forward end of BOAS **174**, which extends radially outward from BOAS **174**. Hook **180** can face forward and hook **182** can face aftward. Hook **184** can be positioned on an aft end of BOAS **174**, extending radially outward from BOAS **174** and facing forward. Hooks **180** and **184** can be received by hooks **108** and **110**, respectively, of case **78**, with a space between an outer surface of hooks **180**, **182** and **184** and an inner surface of case **78**, the distance of the space being identified as $d_3$ in FIG. **6**. As load applying member **92** exerts a radially inward force on lever end **178**, lever **172** pivots about fulcrum **118** and exerts a force on an inner radial surface of BOAS hook **182**, forcing BOAS **174** radially outward and away from rotor tip **88**. As described for clearance control assembly **70**, sensors, such as sensor **132** can be embedded in the inner radial surface of BOAS **174** to measure in real-time rotor tip clearance ($d_2$). Sensors **132** can be in communication with FADEC **131**, which can control actuator **89** to move BOAS **174** based on real-time feedback throughout the operation of the gas turbine engine. Real-time feedback and control can enable system optimization, including tip clearance, and improved efficiency.

Clearance control assemblies **70** and **170** can provide rapid response to rapid changes in operation of a gas turbine engine. Rapid response clearance control can improve efficiency by minimizing rotor tip clearance ($d_2$) and tip leakage, while preventing detrimental tip rub. Use of levers **94** and **178** can enable the positioning of actuators and associated case penetration points outside of the rotor blade containment structure to improve structural integrity and operation and can reduce actuation loads, by locating fulcrum **118** to achieve mechanical advantage. Sensors **132** and FADEC **131** can be incorporated into clearance control assemblies **70** and **170** to provide real-time feedback and control, which can result in additional gains in efficiency.

## DISCUSSION OF POSSIBLE EMBODIMENTS

The following are non-exclusive descriptions of possible embodiments of the present invention.

A clearance control assembly for providing clearance control between a blade outer air seal and an airfoil tip of a gas turbine engine includes an outer case, a first blade outer air seal carrier, a blade outer air seal, an actuator, a load-applying member, and a lever. The first blade outer air seal carrier is positioned radially inward of the outer case. The blade outer air seal is positioned radially inward of and mounted to the blade outer air seal carrier. The load-applying member is positioned to be acted upon by the actuator during operation of the actuator. The lever is connected to the case and is operably in contact with the load-applying member and the first blade outer air seal carrier.

The clearance control assembly of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

A further embodiment of the foregoing clearance control assembly, wherein the lever can be connected to the outer case at a fulcrum.

A further embodiment of any of the foregoing clearance control assemblies, wherein the lever can have first and second ends separated by the fulcrum, and wherein at least one of the first and second ends can include a crowned surface extending radially outward

A further embodiment of any of the foregoing clearance control assemblies, wherein the first end of the lever can be operably in contact with an inner radial surface of the load-applying member and the second end can be operably in contact with an axially extending portion of the first blade outer air seal carrier.

A further embodiment of any of the foregoing clearance control assemblies can further include first and second hooks, a connection member, and third and fourth hooks. The first and second hooks can be positioned radially inward of the outer case. The connection member can extend from the second hook to the lever and can be attached to the lever at the fulcrum. The third and fourth hooks can be positioned radially outward of the first blade outer air seal carrier and can be mounted into the first and second hooks, such that the third hook is positioned between the first hook and the inner surface of the outer case the fourth hook is positioned between the second hook and the inner surface of the outer case.

A further embodiment of any of the foregoing clearance control assemblies, wherein the third and fourth hooks of the first blade outer air seal carrier can contact inner axially extending surfaces of the first and second hooks of the outer case when the lever is in a first position.

A further embodiment of any of the foregoing clearance control assemblies, wherein the third and fourth hooks of the first blade outer air seal carrier can contact the inner surface of the outer case when the lever is in a second position.

A further embodiment of any of the foregoing clearance control assemblies, wherein inner and outer radial surfaces of the third and fourth hooks of the first blade outer air seal carrier can be radially displaced from the inner axially extending surfaces of the first and second hooks and the inner surface of the outer case, respectively, when the lever is in a third position.

A further embodiment of any of the foregoing clearance control assemblies can further include a spring element positioned between the outer case and the load-applying member.

A further embodiment of any of the foregoing clearance control assemblies can further include a second blade outer air seal carrier positioned circumferentially adjacent to the first blade outer air seal carrier, and wherein the lever can be positioned operably in contact with a portion of each of the first and second blade outer air seal carriers.

A further embodiment of any of the foregoing clearance control assemblies can further include a sensor to obtain at least one measurement, which can include distance between the blade outer air seal and the airfoil tip, radial displacement of the blade outer air seal, radial displacement of the blade outer air seal carrier, and combinations thereof.

A method of controlling a clearance between a blade outer air seal and an airfoil tip of a gas turbine engine includes pivoting a lever operably in contact with an axially extending surface of a blade outer air seal or a blade outer air seal carrier and moving the blade outer air seal in relation to the airfoil tip. The lever is pivoted to adjust the radially outward force applied against the axially extending member. The lever is pivoted to 1) increase a radially outward force applied to the axially extending surface or 2) reduce a radially outward force applied to the axially extending surface. The blade outer air seal is 1) lifted in relation to the airfoil tip or 2) lowered in relation to the airfoil tip.

The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional steps:

A further embodiment of the foregoing method can further include obtaining a measurement, which can include distance between the blade outer air seal and the airfoil tip, radial displacement of the blade outer air seal, radial displacement of the blade outer seal carrier, and combinations thereof, and providing the measurement to a control unit. The step of pivoting the lever to adjust the radially outward force applied against the axially extending surface can be done in response to the measurement obtained.

A clearance control assembly for providing clearance control between a blade outer air seal and an airfoil tip of a gas turbine engine includes an outer case having axially separated first and second hooks, a blade outer air seal, an actuator, a load-applying member, and a lever. The first and second hooks are positioned radially inward of the outer case. The blade outer air seal is positioned radially inward of the outer case and has third and fourth hooks. The third hook is positioned between the first hook and the inner surface of the outer case and the fourth hook is positioned between the second hook and the inner surface of the outer case. The load-applying member is positioned to be acted upon by the actuator during operation of the actuator. The lever is connected to the case and operably in contact with the load-applying member and an axially extending surface of the blade outer air seal.

The clearance control assembly of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

A further embodiment of the foregoing clearance control assembly, wherein the lever can include a first end having a crowned surface extending radially outward, a second end having a crowned surface extending radially outward, and a fulcrum positioned between the first and second ends. The fulcrum can be attached to a connection member extending from the second hook of the outer case.

A further embodiment of the foregoing clearance control assembly, wherein the third and fourth hooks of the blade outer air seal can contact radial surfaces of the first and second hooks of the outer case when the lever is in a first position and can contact the inner surface of the outer case when the lever is in a second position.

A further embodiment of the foregoing clearance control assembly can further include a second blade outer air seal positioned radially inward of the outer case. The second blade outer air seal can have an axially extending surface. The lever can be operably in contact with the axially extending surfaces of the first and second blade outer air seals.

A further embodiment of the foregoing clearance control assembly can further include a spring positioned between the outer case and the load-applying member.

A further embodiment of the foregoing clearance control assembly can further include a sensor to obtain at least one measurement, which can include distance between the blade outer air seal and the airfoil tip, radial displacement of the blade outer air seal, and combinations thereof.

## SUMMATION

Any relative terms or terms of degree used herein, such as “substantially”, “essentially”, “generally”, “approximately” and the like, should be interpreted in accordance with and subject to any applicable definitions or limits expressly stated herein. In all instances, any relative terms or terms of degree used herein should be interpreted to broadly encompass any relevant disclosed embodiments as well as such ranges or variations as would be understood by a person of ordinary skill in the art in view of the entirety of the present disclosure, such as to encompass ordinary manufacturing tolerance variations, incidental alignment variations, alignment or shape variations induced by thermal, rotational or vibrational operational conditions, and the like.

While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

The invention claimed is:

**1**. A clearance control assembly for providing clearance control between a blade outer air seal and an airfoil tip of a gas turbine engine, the clearance control assembly comprising:

an outer case comprising a connection member extending from a radially inner surface of the outer case;

a first blade outer air seal carrier positioned radially inward of the outer case;

a blade outer air seal positioned radially inward of and mounted to the first blade outer air seal carrier;

an actuator;

a load-applying member positioned radially inward of the outer case and configured to be acted upon by the actuator during operation of the actuator; and

a lever connected to the connection member of the outer case at a fulcrum, the lever comprising a first end operably in contact with the load-applying member and a second end operably in contact with the first blade outer air seal carrier, the first and second ends separated by the fulcrum.

**2**. The clearance control assembly of claim **1**, wherein at least one of the first and second ends comprises a crowned surface extending radially outward.

**3**. The clearance control assembly of claim **2**, wherein the crowned surface of the first end of the lever is operably in contact with a radially inner surface of the load-applying member and the crowned surface of the second end is operably in contact with an axially extending portion of the first blade outer air seal carrier.

**4**. The clearance control assembly of claim **3** further comprising:

first and second hooks, wherein the first and second hooks are positioned radially inward of the outer case, wherein the connection member extends from the second hook to the lever; and

third and fourth hooks, wherein the third and fourth hooks extend radially outward of the first blade outer air seal carrier and are mounted into the first and second hooks, such that the third hook is positioned between the first hook and the inner surface of the outer case the fourth hook is positioned between the second hook and the inner surface of the outer case.

**5**. The clearance control assembly of claim **4**, wherein the third and fourth hooks of the first blade outer air seal carrier contact inner axially extending surfaces of the first and second hooks of the outer case when the lever is in a first position.

**6**. The clearance control assembly of claim **4**, wherein the third and fourth hooks of the first blade outer air seal carrier contact the inner surface of the outer case when the lever is in a second position.

**7**. The clearance control assembly of claim **4**, wherein inner and outer radial surfaces of the third and fourth hooks of the first blade outer air seal carrier are radially displaced from the inner axially extending surfaces of the first and second hooks and the inner surface of the outer case, respectively, when the lever is in a third position.

**8**. The clearance control assembly of claim **1**, further comprising:

a spring element positioned between the outer case and the load-applying member.

**9**. The clearance control assembly of claim **1**, further comprising:

a second blade outer air seal carrier positioned circumferentially adjacent to the first blade outer air seal carrier, and wherein the lever is positioned operably in contact with a portion of each of the first and second blade outer air seal carriers.

**10**. The clearance control assembly of claim **1**, further comprising:

a sensor to obtain at least one measurement selected from the group consisting of distance between the blade outer air seal and the airfoil tip, radial displacement of the blade outer air seal, radial displacement of the blade outer air seal carrier, and combinations thereof.

**11**. A method of controlling a clearance between a blade outer air seal and an airfoil tip of a gas turbine engine, the method comprising:

pivoting a lever connected to an outer case and operably in contact with a load-applying member at a first end of the lever and an axially extending surface of at least one of a blade outer air seal and a blade outer air seal carrier at a second end of the lever to adjust a radially outward force applied against the axially extending surface, wherein pivoting the lever results in at least one of 1) increasing a radially outward force applied to the axially extending surface and 2) reducing a radially outward force applied to the axially extending surface; and

moving the blade outer air seal in relation to the airfoil tip, wherein moving the blade outer air seal comprises at least one of the steps including 1) lifting the blade outer air seal in relation to the airfoil tip and 2) lowering the blade outer air seal in relation to the airfoil tip;

wherein the outer case has axially separated first and second hooks positioned radially inward of the outer case to engage third and fourth hooks of the one of the blade outer air seal and a blade outer air seal carrier, and wherein a connection member extending from the second hook is attached to the lever at a fulcrum.

**12**. The method of claim **11**, further comprising:

obtaining a measurement selected from the group consisting of distance between the blade outer air seal and the airfoil tip, radial displacement of the blade outer air seal, radial displacement of the blade outer seal carrier, and combinations thereof;

providing the measurement to a control unit; and

wherein pivoting the lever to adjust the radially outward force applied against the axially extending surface is done in response to the measurement obtained.

**13**. The method of claim **11**, wherein pivoting the lever causes the blade outer air seal to move to a position selected from the group consisting of an innermost radial position, an outermost radial position, and a middle radial position, wherein the middle radial position comprises any radial position between the innermost and outermost radial positions.

**14**. A clearance control assembly for providing clearance control between a blade outer air seal and an airfoil tip of a gas turbine engine, the clearance control assembly comprising:

an outer case having axially separated first and second hooks, the first and second hooks positioned radially inward of the outer case;

a first blade outer air seal positioned radially inward of the outer case and having third and fourth hooks, the third hook being positioned between the first hook and a radially inner surface of the outer case and the fourth hook being positioned between the second hook and the radially inner surface of the outer case;

an actuator;

a load-applying member positioned to be acted upon by the actuator during operation of the actuator; and

a lever connected to the outer case and operably in contact with the load-applying member and an axially extending surface of the blade outer air seal, wherein the lever comprises:

a first end having a crowned surface extending radially outward;

a second end having a crowned surface extending radially outward; and

a fulcrum positioned between the first and second ends, wherein the fulcrum is attached to a connection member extending from the second hook of the outer case.

**15**. The clearance control assembly of claim **14**, wherein the third and fourth hooks of the blade outer air seal contact radial surfaces of the first and second hooks of the outer case when the lever is in a first position and contact the radially inner surface of the outer case when the lever is in a second position.

**16**. The clearance control assembly of claim **14**, further comprising:

a second blade outer air seal positioned radially inward of the outer case and having an axially extending surface, wherein the lever is operably in contact with the axially extending surfaces of the first and second blade outer air seals.

**17**. The clearance control assembly of claim **14**, further comprising:

a spring positioned between the outer case and the load-applying member.

**18**. The clearance control assembly of claim **14**, further comprising:

a sensor to obtain at least one measurement selected from the group consisting of distance between the blade outer air seal and the airfoil tip, radial displacement of the blade outer air seal, and combinations thereof.

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